ARIZONA DEPARTMENT OF TRANSPORTATION

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EVALUATION OF TRAFFIC OPERATION COUNTER-MEASURES TO REDUCE AIR POLLUTION

State of the Art

Final Report

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16. ABSTRACT

The increasing air pollution problem in metropolitan areas presents a serious threat to the health of the public. It has been reported that during the years 1983-85, 76 U.S. cities had violated the ozone pollution standards and 81 cities violated the limits on carbon monoxide. Environmental Protection Agency has begun enforcement actions against cities that either have failed to develop an approved plan to reduce the pollution or have failed to carry out previously approved plans.

Motor vehicle emissions are the major contributors to air pollution in urban areas. An effective solution to this problem is the reduction of motor vehicle emissions by means of a comprehensive transportation plan. This plan includes short term solutions such as automobile use management during certain days of the week, traffic management strategies, short term transit strategies, and parking management.

This study: 1) developed a state-of-the-art report on the topic of "Evaluation of Traffic Operation Countermeasures to Reduce Air Pollution;" 2) recommended that further research be done to assess the effectiveness of different control strategies and motorist information systems on air pollution; 3) developed a research work plan for the proposed topic.

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INTRODUCTION

The increasing air pollution problem in metropolitan areas presents a serious threat to the health of the public. With the deadline for attainment of air quality standards set for December 31st, numerous metropolitan areas around the country will not meet the deadline.

It has been reported that during the years 1983-85, 76 U.S. cities had violated the ozone pollution standards and 81 cities violated the limits on carbon monoxide. Congress has not decided what will happen to cities that fail to meet the standards by the December 31, 1987 deadline. However, Environmental Protection Agency (EPA) has begun enforcement actions against cities that either have failed to develop an approved plan to reduce the pollution or have failed to carry out previously approved plans.

Motor vehicle emissions are the major contributors to air pollution in urban areas. An effective solution to this problem is the reduction of motor vehicle emissions by means of a comprehensive transportation plan. This plan includes short term solutions such as automobile use management during certain days of the week, traffic management strategies, short term transit strategies and parking management. Long term solutions are also included such as High Occupancy Vehicle (HOV) priority lanes, long range transit, bicycling, areawide ridesharing, alternative work schedules, and telecommunications.

Although some cities have no chance of meeting federal standards within a reasonable time frame (two or three years), other cities were removed from the carbon monoxide list. For example, Los Angeles, California needs to reduce its ozone pollution by 70 percent to meet the standards, yet removing all automobiles from the highways would only result in a 50 or 55 percent reduction. Tucson, Arizona is one of the cities that was removed from the carbon monoxide list. The main factor causing the reduction was reported to be improved emission controls on automobiles, and a lesser factor was an improved road network.

It is the objective of this report to investigate the impact of traffic engineering strategies on air pollution in urban areas and provide recommendations on the extent of further studies in this area.

RESEARCH OBJECTIVES

The objectives of this study are: 1) to develop a state-of-the-art report on the subject of "Evaluation of Traffic Operation Countermeasures to Reduce Air Pollution"; 2) to recommend whether research should be done on this subject; and 3) to develop a research work plan for any research recommended. Any research recommended would lead to determination of the effect of selected traffic countermeasures on air pollution and the establishment of guidelines for traffic signal control strategies on arterials and freeway ramps to minimize carbon monoxide and ozone pollution. This study was comprised of the following tasks:

1) Review of all available research studies identifying the following traffic engineering strategies which reduce air pollution in urban areas:
   a) Traffic signal elements: Timing, including progression schemes, types of controllers (pretimed and actuated), types and location of detectors, flashing mode, unwarranted signals.
   b) Traffic operation elements: Parking, turning movements, transit accommodations, exclusive lanes, one-way streets, added lanes, midblock friction.
   c) Traffic Regulation Elements: speed limits, right-turn-on-red, parking prohibition, turn prohibition.
2) Review, evaluate, and summarize the current traffic engineering strategies which reduce air pollution.
3) Provide recommendations on the scope of further studies.
4) Develop a detailed work plan for any recommended research, establish the anticipated project duration and estimated budget.

BACKGROUND INFORMATION

The major sources of pollution are nature, industrial processes, transportation, solid waste and miscellaneous sources. Transportation includes motor vehicles both on and off highways. It is estimated that on a global basis, nature accounts for more than 90 percent of the carbon monoxide (CO) in the air. Of the 10 percent of CO that is man-made, about 70 percent is attributed to highway vehicles [1]. As for other pollutants, motor vehicles emit about 33 percent of man-made hydrocarbons (HC) and nitrogen oxides (NO_x), about 6 percent of total suspended particles, and only 1.5 percent of sulfur oxides (SO_x). Transportation-related pollution accounts for an average of 60 percent of the total pollutants in the atmosphere for the major metropolitan areas in the United States. Of this, the private automobile contributes from 90 to 95 percent of the air pollution.

Vehicular emissions of air pollutants are usually measured in grams per vehicle mile of travel and are related to several factors including vehicle type and age, ambient temperature, and altitude. The operating cycle, which consists of starts and stops, speed changes, and idling time, is an important factor in determining motor vehicle emission quantities. A large portion of CO and HC are emitted during cold starts of the engine.

The general relationships between speed and emissions are illustrated in Figures 1, 2 and 3. Generally speaking, CO emissions decrease with speed, a similar relationship occurs in the

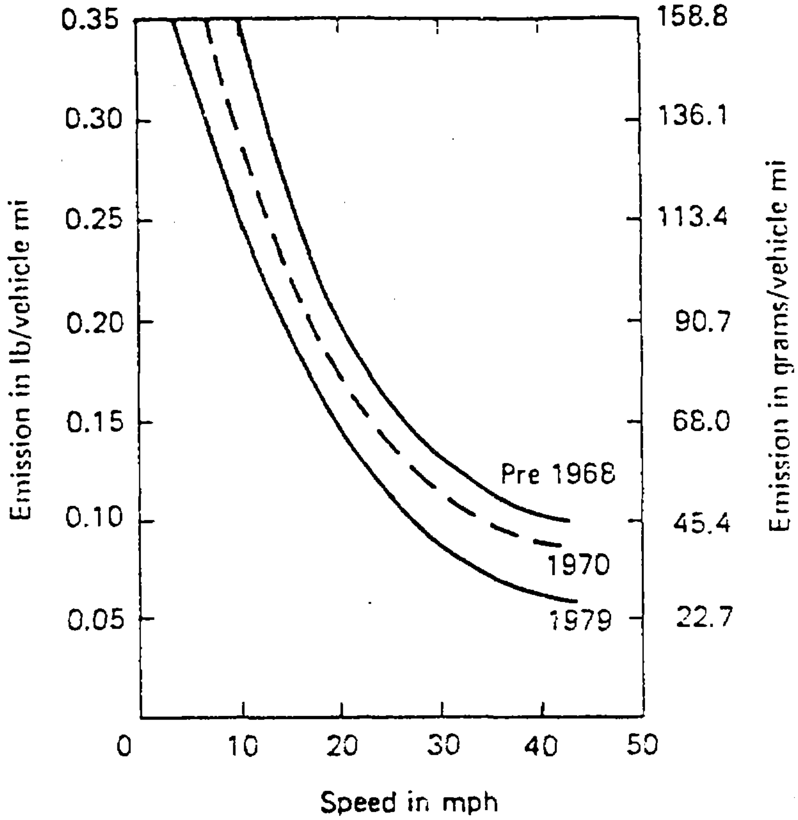

FIGURE 1. CARBON MONOXIDE VEHICULAR EMISSION VERSUS SPEED
Source: Reference 2

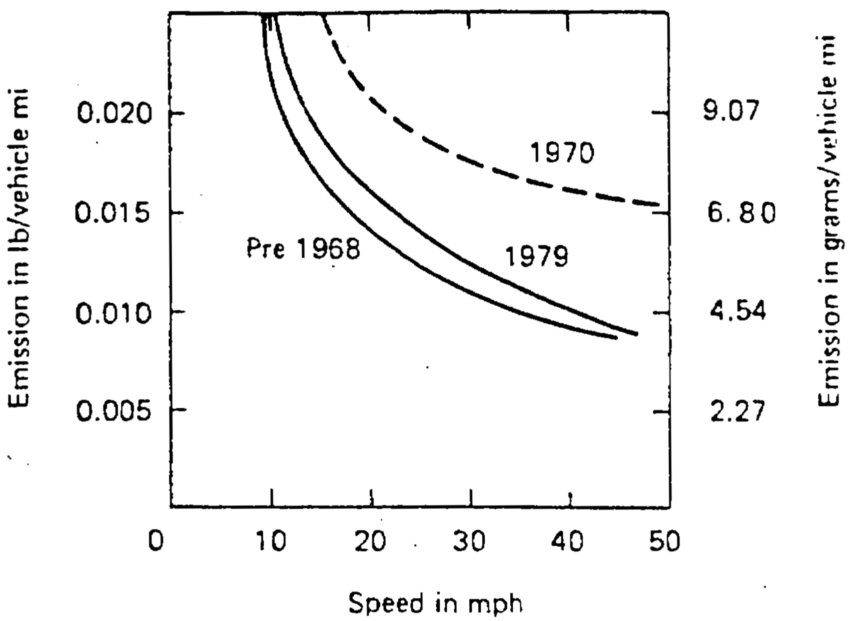

FIGURE 2. HYDROCARBON VEHICULAR EMISSION VERSUS SPEED
Source: Reference 2

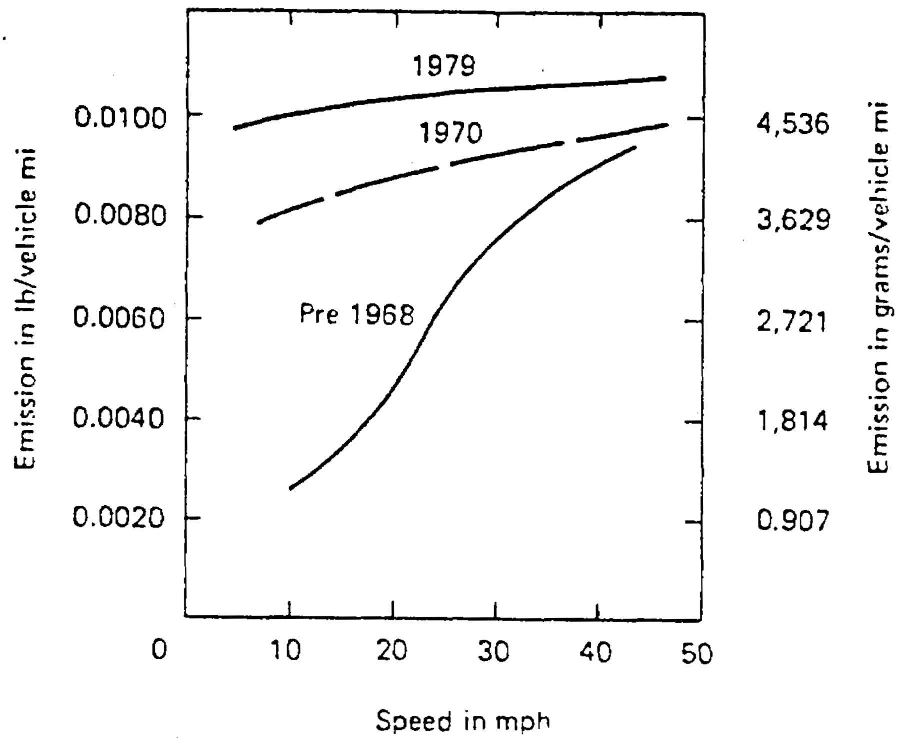

FIGURE 3. NITROGEN OXIDE VEHICULAR EMISSION VERSUS SPEED
Source: Reference 2

case of HC emissions up to about 30 to 40 miles per hour [2]. Emissions of NO_x generally increase with speed, resulting in a pattern opposite to the previous emissions.

The EPA has developed a computer model that estimates the emissions resulting from various combinations of traffic flows, vehicle mixes, and other factors. A simplified model for CO based on the EPA program has been proposed in a previous study [3]. This proposed model utilizes several nomographs based on a typical 1980 vehicle mix for various altitudes and ambient temperatures. Figure 4 displays the family of curves corresponding to altitudes up to 4000 feet above sea level. It is important to notice the sharp decline of the curves in the speed range of 5 and 15 miles per hour. This observation emphasizes the importance of minimizing traffic speed reduction below 15 miles per hour.

Although truck traffic accounts for as much as 50 percent of the traffic volume on truck routes, it plays a relatively minor role in air pollution. Most large trucks are powered by diesel engines which produce pollutants in amounts considerably less than gasoline engines. Furthermore, truck traffic is more constant throughout the day, with less peaking during normal morning and afternoon commuting hours. Since air pollution has a temporal as well as geographic dimension, the time distribution of truck travel tends to lessen the impact of emissions by these vehicles.

LITERATURE REVIEW

This section of the report summarizes previous work related to traffic engineering strategies and their significance to air pollution. The summary is divided into three sections: general elements, traffic signal elements, and traffic operation and regulation elements.

General Elements:

A previous study resulted in the development of a freeway and an arterial model, and their application in assessing the impacts of traffic-management strategies [4]. Previously developed models were modified to include energy and air pollution impacts, and to include spatial and modal demand shifts due to freeway and arterial traffic management strategies. The application of the model to a freeway section in Los Angeles concluded that priority entry-control operations were more effective than normal entry-control operations, and an exclusive bus and car-pool lane was more effective than an exclusive bus lane.

In another study, two models were developed: a vehicle emissions model and an urban transportation model [5]. Emissions controls give smaller emission rates without affecting the total vehicle mileage, while transportation controls reduce traffic by applying parking restrictions, staggered work hours, promotion of mass transportation, commuter and gasoline taxes.

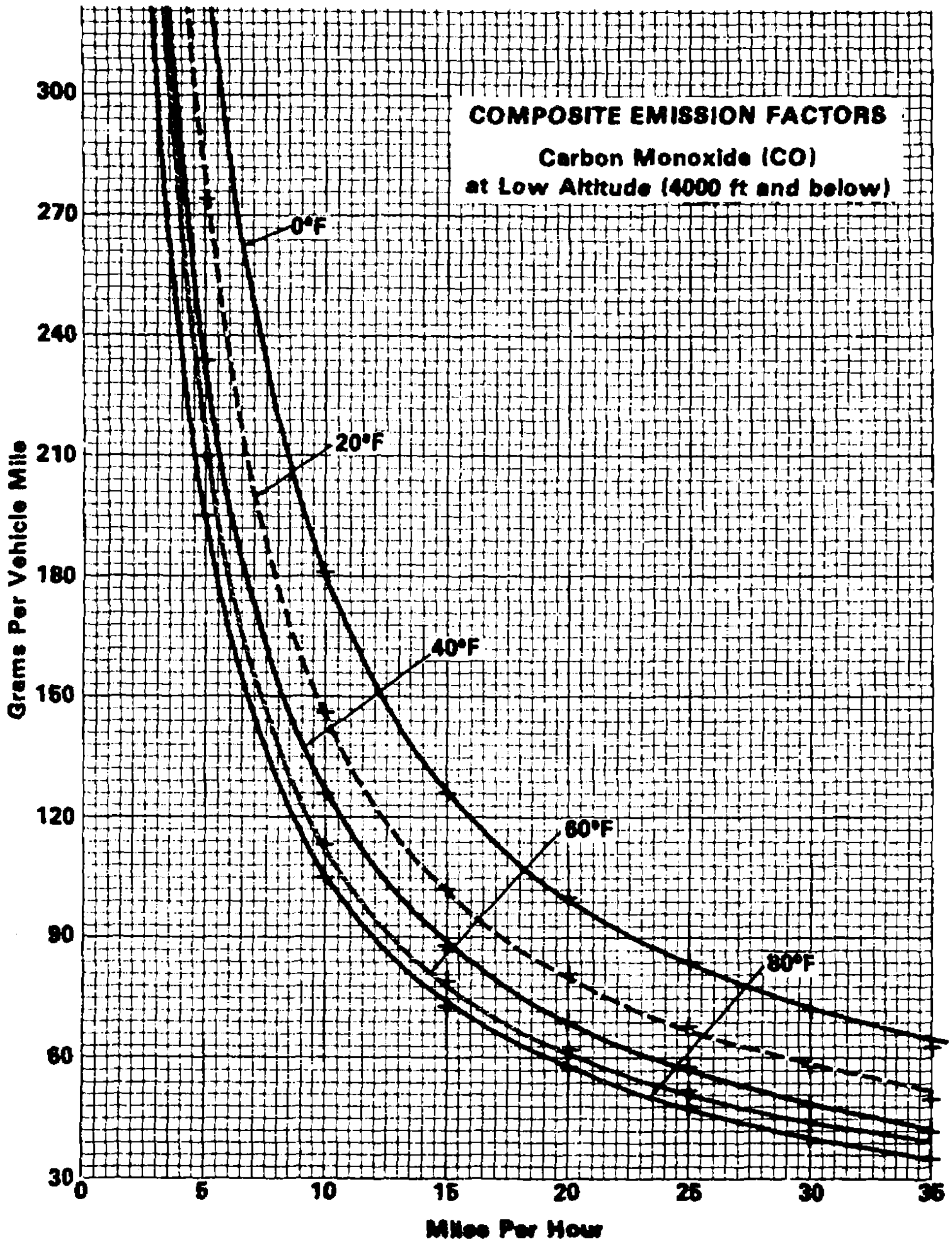

FIGURE 4. CARBON MONOXIDE EMISSIONS FACTORS - 1980 VEHICLE MIX

Source: Reference 3

Air quality computer models have been developed and utilized to evaluate traffic operation countermeasures. The California Line Source Dispersion Model (CALINE4) uses traffic emissions, site geometry, and meterology to predict air pollution concentrations near roadways [6]. The model predicts the amounts of CO, HC, and NO_X near intersections, parking lots, elevated or depressed freeways, and within canyons.

Sensitivity studies of the CALINE4 model resulted in the development of a Meteorological Severity Index (MSI) [7]. This index represents the relationship between meteorological parameters that contribute to worst case CO concentrations near roadways.

Theoretical techniques have been investigated to predict air pollution levels near roads from traffic. A method which uses data on traffic flows, vehicles speeds, road layouts and meteorological conditions was developed and tested in the United Kingdom [8]. The method assumes Gaussian type dispersion of the pollutants. Model calibration was implemented at two sites. This prediction method can be used in the comparative evaluation of the air pollution impact of alternative road schemes.

In Arizona, the Maricopa Association of Governments (MAG), the regional air quality planning agency designated to address air pollution problems, developed extensive plans for carbon monoxide and ozone for the Maricopa County area [9,10]. Appropriate regional traffic models (Urban Transportation Planning System, UTPS) were utilized to develop base year traffic forecasts for the Maricopa County area. These regional models provided estimates for assessing overall regional patterns of air quality and concentrations of pollutants (CO and ozone). An intersection traffic model was used to test the effectiveness of different traffic strategies at the local level (TRANSYT 7F computer model). Composite fleet emission factors for a range of travel speeds and ambient temperatures were developed for the base year and future years using the MOBILE THREE model. A computer program called TRFCONV was developed to combine the emission factors from MOBILE THREE and the traffic volumes from UTPS to generate total emissions and identify their approximate origin. Intersection specific concentrations were projected using the CALINE 4/V9-PG computer model.

The regional and intersection models were used to estimate the effectiveness of 20 air pollution control measures in reducing carbon monoxide and ozone emissions. The study concluded that, by instituting winter daylight savings time, an estimated reduction of 21.6 percent and 6.2 percent can be achieved for CO and ozone, respectively. Two of the 20 measures evaluated were traffic related; they were reversible lanes on arterials and short range transit improvements. The estimated reduction in CO and ozone was reported to be 1.3 percent and 0.3 percent, respectively, for the reversible lane measure. Thus, the study concluded that reversible lanes would have much less impact on air pollution than planning and transportation policy strategies.

The study did not include traffic signal synchronization in their assessment because the 1987 Arizona air quality legislation requires synchronization of traffic signals on streets with average daily traffic volumes over 15,000. The presence of a synchronized system was incorporated in the traffic and air quality model calibration process and is reflected in the base system forecasts.

Other traffic strategies, such as HOV lanes on freeways, freeway surveillance, ramp metering, and signage were not assessed for base year 1987, instead, they were considered as 1995 planned strategies. The models estimated reductions of CO emissions of 2.7 percent and 0.5 percent from base for HOV lanes and freeway surveillance, respectively. These percentages were reported to be 1.0 percent and 0.10 percent for ozone emissions.

Traffic Signal Elements:

This section reports on past studies related to street traffic signals and freeway ramp metering. The most significant work related to signal timing and air pollution was initiated in California in 1983. The program was called Fuel-Efficient Traffic Signal Management Program (FETSIM), and it was implemented in 41 cities in California [11]. The participating cities used the TRANSYT-7F computer simulation model to retime their signal systems which ranged in size from 10 to 267 signals. Although the goal of this program was to minimize delays, stops, and fuel consumption, the outcome would be reduction in CO, HC, and NO_X emissions. It was reported for selected cities that, on average, system travel times were reduced by 6.5 percent, stops and delays were reduced by more than 14 percent, and fuel consumption was reduced by 6.0 percent.

A similar project was conducted for a 70 intersection network in the city of Garden Grove, California [12]. This project resulted in per-intersection annual reductions of 6015 vehicle hours of delay, 489,643 stops and 7166 gallons of gasoline. Annual HC emissions for the entire network were reduced by 28.32 tons, CO emissions by 442 tons, and NO_X emissions by 18.62 tons.

A recent study was conducted in the Phoenix Metropolitan area to assess the impact of traffic signal coordination improvements on CO emissions [13]. Three study sites were chosen to test optimum signal coordination plans developed by the TRANSYT-7F computer model. The signal systems at two of these sites were already coordinated, and the third signal system was fully actuated. This study measured the impact on traffic flow caused by changing the system to a fixed-time coordinated system. It was found that application of the TRANSYT-7F program to the already coordinated systems did not improve traffic flow. However, changing from an actuated controller to a fixed-time coordinated system did improve traffic flow. It was estimated that the number of vehicles stopping was decreased by 8 percent. A decrease in the

CO concentration was reported at 2 to 7 percent. However, these changes are difficult to measure due to the large impact of wind on the accuracy of the measures.

Freeway control and management strategies have been adopted by numerous cities to improve traffic flow. Entrance ramp metering has been proven effective in reducing traffic delay and increasing average speeds. In six cities where ramp metering was implemented, average freeway speeds increased by 30 percent; the increase was reported to be 22 percent after taking delays at the ramp metering signals into account [14].

In a similar study conducted in Phoenix, Arizona, three ramp metering strategies were assessed using a computer freeway model (FREQ6PE) [15]. The strategies were: 1) no ramp metering, 2) ramp metering with the existing fixed metering rates, and 3) ramp metering with computer optimized metering rates. The model was applied to 16 ramps metered on 15 directional miles of Interstate 17 in Phoenix. Carbon monoxide emissions and fuel consumption were estimated based on the speed and number of vehicles. The study concluded that ramp metering does not have any significant impact on CO emissions using the FREQ6PE computer model. Two reasons were hypothesized. First, although ramp metering reduces congestion on the freeway during peak periods, it has no impact when congestion does not occur. Since congestion occurs only for several hours per day on I-17, there is a small amount of time that ramp metering will have an impact. Second, ramp metering can increase freeway speeds during peak periods and, therefore, decrease CO emissions on the mainline, but more CO is created at the on-ramps by the waiting vehicles.

Traffic Operation and Regulation Elements:

This section reports on studies related to parking management, one-way movements, speed limits, right turn on red, turn prohibition and transit accommodations. The freeway and arterial model cited in the previous section [4] evaluated the effectiveness of preferential bus and car-pool lanes on freeways. The study concluded that priority entry control results in less travel-time and air pollution and higher fuel consumption and vehicle-kilometers traveled.

Seven short-term transportation control strategies were identified as likely candidates to provide short-time reductions in CO emissions for motor vehicles: inspection, maintenance, traffic flow techniques, bypassing through traffic, improvements in public transportation, motor vehicle restraints, and work schedule changes [16].

A comprehensive study was conducted to provide support for the development of revised Carbon Monoxide State Implementation Plan (SIP) elements for Pima and Maricopa counties in Arizona [17]. Twelve categories of transportation measures were examined which covered a wide spectrum of traffic flow improvements, short and long term transit strategies, alternative work hours, and auto use management. Four of the twelve categories were found relevant to the current state-of-the-art report: traffic flow improvements, high occupancy vehicle priority lanes, parking management, and short range transit improvements.

The report concluded that in both Maricopa and Pima Counties, the most effective traffic flow improvement strategy is to solve traffic congestion problems and associated CO at a localized level. Suggested measures include reversible lanes, lagged left turn phasing, and a "pacer" system to inform motorists of the proposed speed to attain signal synchronization. A 4 to 16 percent increase in average speed on affected facilities was reported to be the national effectiveness experience, and a high level of confidence in effectiveness estimates given mandatory compliance with such improvements was concluded.

Nationally, the effectiveness of high occupancy vehicle priority lanes was reported to result in a 5 to 10 percent reduction in peak period vehicle-miles of travel; the level of confidence in the effectiveness estimates is high. Compliance with such a measure is voluntary, however. Furthermore, it was pointed out that congestion may not be extensive enough on freeways to make HOV lanes effective in reducing emission levels on a regional basis.

Although parking management is viewed as primarily a long-term strategy, short-range actions can be taken to alleviate specific localized congestion and associated CO problems within well-defined activity centers. A 0.5 percent regional CO emissions reduction was reported as a national effectiveness experience with parking management. Level of confidence in effectiveness estimates is considered low with compliance being mandatory or voluntary.

The report defined short range transit improvements to include measures such as: service expansion (increasing frequency and route changes); operational changes (transit priority schemes including signal preemption); and fare policy (free/low fares). National experience indicated that emissions reductions of 10 to 20 percent may be achieved on specific transportation corridors. The level of confidence in effectiveness estimates for these improvements was reported to be high and the compliance is generally voluntary.

From this literature review, it can be concluded that transportation planning and policy issues implemented on a long term basis result in higher reductions of air pollution than short term traffic improvement measures. Furthermore, it was concluded that an estimated reduction of CO emissions may reach 7 percent for optimized coordinated signals and only 1 percent for ramp metering strategies. The effectiveness of these traffic strategies varies from one site to another and is highly dependent on local traffic and land use conditions. All previous studies evaluated individual sites without considering the overall system of freeways, arterials and local streets. In addition, a motorist information system on a freeway corridor and the surrounding street system can have significant impacts on traffic flow and air pollution. The Transportation and Road Research Laboratory reported that the lack of a motorist information system on the network in the United Kingdom resulted in up to 15 percent extra trips. This additional travel could have been prevented by proper signing.

CURRENT PRACTICE

A two page survey was developed to review current practice with respect to traffic engineering improvements and their impact on air pollution. Figure 5 displays the survey form. As the form indicates, the first question was attitudinal in nature where respondents were asked to rank a list of traffic engineering strategies for reducing air pollution by order of importance. They were also asked to list other strategies that they thought should be considered, but were not included on the list provided. The second and the third questions asked whether public agencies adopted operation strategies to reduce air pollution, and whether they had written plans or guidelines to implement such strategies.

The survey was mailed to all members of the AASHTO Traffic Engineering Subcommittee (the State Traffic Engineers from each of the 50 states), selected members of the National Committee on Uniform Traffic Control Devices, and selected members of the Urban Traffic Engineers Council. The Urban Traffic Engineers Council is a council whose membership consists of traffic engineering officials (all Institute of Transportation Engineers members) of any city, town, township, county, or other urbanized local government unit who have common transportation engineering interests and direct responsibilities in traffic operation.

Seventy-two responses were received. Thirty-two of the 72 respondents answered "yes" to question 2, which means that their agency has adopted traffic operation strategies to reduce air pollution. Thirty-nine answered "no," and one did not complete this question. Twelve of the respondents indicated that the traffic operation strategies they adopted are aimed at reducing travel time delays, and air pollution reduction is a by-product of this process.

Sixty-five of the 72 answered "no" to question 3, 6 indicated "yes," and 1 left the question blank. The six positive responses meant that these agencies have written plans or guidelines to implement traffic strategies to reduce air pollution.

One written set of plans were received from the Utah Department of Transportation, Safety Division. The plans were related to retiming signals at three selected locations. Funds for conducting the study were obtained from the Petroleum Violation Escrow Account (PVEA). The PVEA is derived from negotiated settlements and legal judgments against oil companies by the federal government for price overcharges on crude oil and refined petroleum products during the period of price control regulations from September 1973 through January 1981. Although the study was aimed at reducing energy consumption, air pollution reduction guidelines also resulted.

The increasing air pollution problem in metropolitan areas presents a serious threat to the health of the public. With the deadline for attainment of air quality standards set for December 31, numerous metropolitan areas around the country will not meet the deadline. Potential result is a cutoff in federal highway funding. It has been reported that motor vehicle emissions are the major contributors for air pollution in urban areas. Traffic engineering strategies have been proposed to reduce motor vehicle emissions.

The purpose of this survey is to review current plans and practices set by public agencies to deal with the problem of air pollution in the U.S. Your response to this survey will be greatly appreciated.

1. What traffic engineering strategies do you think are important to reduce motor vehicle emissions? Please rank these strategies by order of importance.

_____Type of intersection control (stop sign, flashing, pretimed signal, or actuated signal)

_____Signal progression

_____Ramp metering on freeways

_____Parking prohibition

_____Turning movement prohibition

_____Intersection channelization

_____Transit vehicle priorities

_____Right-turn-on-red

_____Location of signal detectors

FIGURE 5. SURVEY FORM

_____Speed limit

_____Pedestrian signals

_____Signal timing

Please list other strategies that you think should be considered

____

____

____

____

2. Does your agency now adopt traffic operation strategies to reduce motor vehicle emissions?

_____Yes

_____No

3. Does your agency have any written plans or guidelines to implement traffic strategies for the purpose of reducing motor vehicle emissions?

_____Yes (please provide a copy)

_____No

4. Name______________________________________

Agency______________________________________

Please respond by October 15.

Thank you for your help.

FIGURE 5. SURVEY FORM (continued)

Contacts were made with the other five agencies to collect more information on their written plans. Florida Department of Transportation responded that they use the TRANSYT 7F computer program to time their signals with the goal of increasing traffic flow efficiency and reducing emissions. North Carolina Department of Transportation (Charlotte office) indicated that the state is updating their ten year state plan to improve traffic flow efficiency and reduce emissions. Some of their programs instituted are vehicular emissions checks, ride sharing programs, a demonstration project for bus preemption, and identification of critical intersections (hot spots) along major corridors. The identification of four hot spots in the Charlotte area is perhaps the most relevant to this report. Transportation System Management strategies were implemented at these sites, with retimed signals being the most effective countermeasure.

The third agency contacted was the Automobile Club of Southern California. Officials in this agency informed the author about the "commuter computer" and ride sharing programs implemented in the southern California metropolitan area to reduce vehicle-miles of travel and, consequently, air pollution. The "commuter computer" program is a computerized data base which matches individuals, employees of public agencies and public companies to share rides.

Two agencies in Texas indicated that plans have been developed in two counties to deal with the problems of air quality. The North Central Texas Council of Government provided information on current and proposed transportation control measures to attain ozone standards in Dallas County and Tarrant county. These two counties cover the metropolitan area of Dallas and Fort-Worth (3,500 square miles). Included in the State Implementation Plan are traffic measures such as signal timing, signal progression, and low cost intersection improvements.

Question 1 responses were tallied to identify the most important strategies ranked by the respondents. Table 1 documents the top three strategies and their corresponding frequencies. It is clear from this table that signal progression was viewed as number one strategy. Signal timing received a higher response as a second rank strategy than control type and signal progression. Control type and signal timing were tied in numbers of responses for third rank. It is interesting to observe that the top three strategies are traffic signal related strategies.

The mean of all ranks given to each of the 12 strategies was calculated and provided in Table 2. The reason for determining the mean is that the analysis of the ranks did not lead to a clear consensus among the respondents to the ranking of different strategies. The statistics of Table 2 indicated clearly that the top three strategies are the signal related strategies, followed by right-turn-on-red. It is obvious, therefore, that any further research work should be aimed at traffic signal strategies.

TABLE 1. RESPONSE RESULTS TO QUESTION 1

Ranking	Control Type	Strategy Description Signal Progression	Signal Timing	Others*
1	17	32	18	5**
2	10	21	28	13
3	15	11	15	31

*The responses of the remaining nine strategies are combined.

**These responses ranked the following strategies as being #1:

- Ramp metering on freeways
- Transit vehicle priorities
- Right-turn-on-red (RTOR)
- Location of signal detectors
- Turning movement prohibition

TABLE 2 RESPONSE MEANS TO QUESTION 1

Strategy	Response Mean	Strategy	Response Mean
Signal Progression	2.00	Transit vehicle priorities	6.87
Signal Timing	2.36	Ramp Metering	7.8
Control Type	3.51	Parking Prohibition	7.12
RTOR	5.53	Detector Location	7.25
Turning Movement Prohibition	6.39	Speed Limit	8.78
Intersection Channelization	6.83	Pedestrian Signal	10.58

Note: Lower value indicates higher priority

RECOMMENDATION FOR FURTHER RESEARCH

The assessment of the literature and current practice suggests that the level of knowledge about traffic control strategies in a system context and their effect on air pollution needs improvement. A comprehensive research study needs to be conducted to assess the effectiveness of different control strategies and motorist information systems on air pollution. A large scale transportation network composed of one or more freeway corridors and a street grid system should be considered. Computer simulation coupled with field data collection should be used to determine the anticipated changes in air pollution emissions for the proposed strategies. The following section presents a detailed work plan for carrying out this research.

DETAILED WORK PLAN

TASK 1 - IDENTIFY STRATEGIES TO BE ASSESSED

Three levels of traffic operation strategies are proposed for assessment:

1. Grid Network Traffic Signal Coordination: "TRANSYT 7F" computer program may be utilized to develop signal settings to optimize three possible objective functions:
   - o Network vehiclular delay
   - o Network passenger delay
   - o Network air pollution

The first function is the traditional objective function used in most timing schemes. The second objective function considers transit vehicle interaction with the regular vehicular traffic, and the third objective function is aimed at reducing air pollution emissions only.

2. Freeway HOV lanes and Ramp Metering:

   Three operational strategies are proposed:
   - o No ramp control
   - o Optimum ramp metering rate
   - o Optimum ramp metering rate with preferential treatment for High Occupancy Vehicles.

   The appropriate "FREQ" computer program should be used to determine metering rates for the freeway corridor.

3. Freeway Surveillance, Ramp Metering, and Signage:

   Video surveillance can be used to detect a major accident on a freeway. Upstream traffic could be warned with electronic variable message signs and entrance ramps could be closed to avoid major jams. This system would result in an increase in the freeway capacity; however, no specific figures are available regarding this increase. Three possible scenarios ranging between 0 percent and 10 percent in capacity increase can be assessed. The closing of a ramp would result in traffic diversion to the street system which should be captured in the first section of this task.

Twenty-seven possible cases would need to be assessed for the proposed levels of operation strategies. Each case represents a specific combination of street signal coordination, freeway ramp metering, and freeway surveillance.

TASK 2 - SELECT TRANSPORTATION NETWORK

A network composed of two major freeways and a street grid network is proposed for the study. A portion of the road network in the Phoenix metropolitan area could be a good candidate for the study.

TASK 3 - ADAPT A COMPUTER SIMULATION MODEL

The "TRAF" computer system is proposed for this study. TRAF contains several submodels, four of which are relevant to this study:

1. TRAFLO: a macroscopic model used to simulate traffic flow on streets. It has a traffic assignment algorithm.
2. FREEFLO: a macroscopic model used to simulate traffic flow on freeways. Provisions for ramp metering and preferential control are made in this model.
3. NETSIM: a microscopic model used to simulate traffic movements on streets with detailed information on traffic management strategies. It contains fuel consumption and vehicular emission options, which would permit the user to estimate excess fuel consumed as well as air pollution emissions for any given simulation run.
4. FREESIM: a microscopic model used to simulate traffic movements on freeways.

The advantage of using the TRAF system is that all four submodels are integrated. This means that the user can overlay the grid system on the freeway corridor and determine the impact of certain traffic strategies on the system measures of effectiveness (delay, queues, fuel consumption, air pollution, etc.). Furthermore, the user can conduct analyses at the regional level (macroscopic) or at the localized level (microscopic).

TASK 4 - EVALUATE SIMULATION RESULTS

Twenty-seven simulation runs are proposed to be conducted. Field data are required to calibrate the simulation model for the base run, which correspond to no ramp metering, no freeway surveillance, and network vehicular delay objective functions. Data needed are measurements of air pollution emissions, vehicular delays and queue formation. For each run, the model estimates stopped delays, queue length, excess fuel consumed, CO emissions, HC emissions, and NO_X emissions. These measures are then used to judge the effectiveness of these different strategies.

TASK 5 - DEVELOP GUIDELINES

Results obtained from the 27 runs may lead to the development of guidelines. These guidelines may assist traffic engineers and transportation planners in deciding when to use a specific traffic operation strategy and at what level it is justifiable. More simulation runs may be deemed necessary to develop practical and useful guidelines.

TASK 6 - PREPARE FINAL REPORT

Prepare a final report which documents all assumptions, traffic data, simulation runs, and findings of the research project.

ANTICIPATED PROJECT DURATION: 12 Months

ESTIMATED BUDGET: $70,000

LIST OF REFERENCES

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